Chair of Structural Analysis

IGSSE-Project 1-2

Isogeometric Shape Optimization of Surface Coupled Structures

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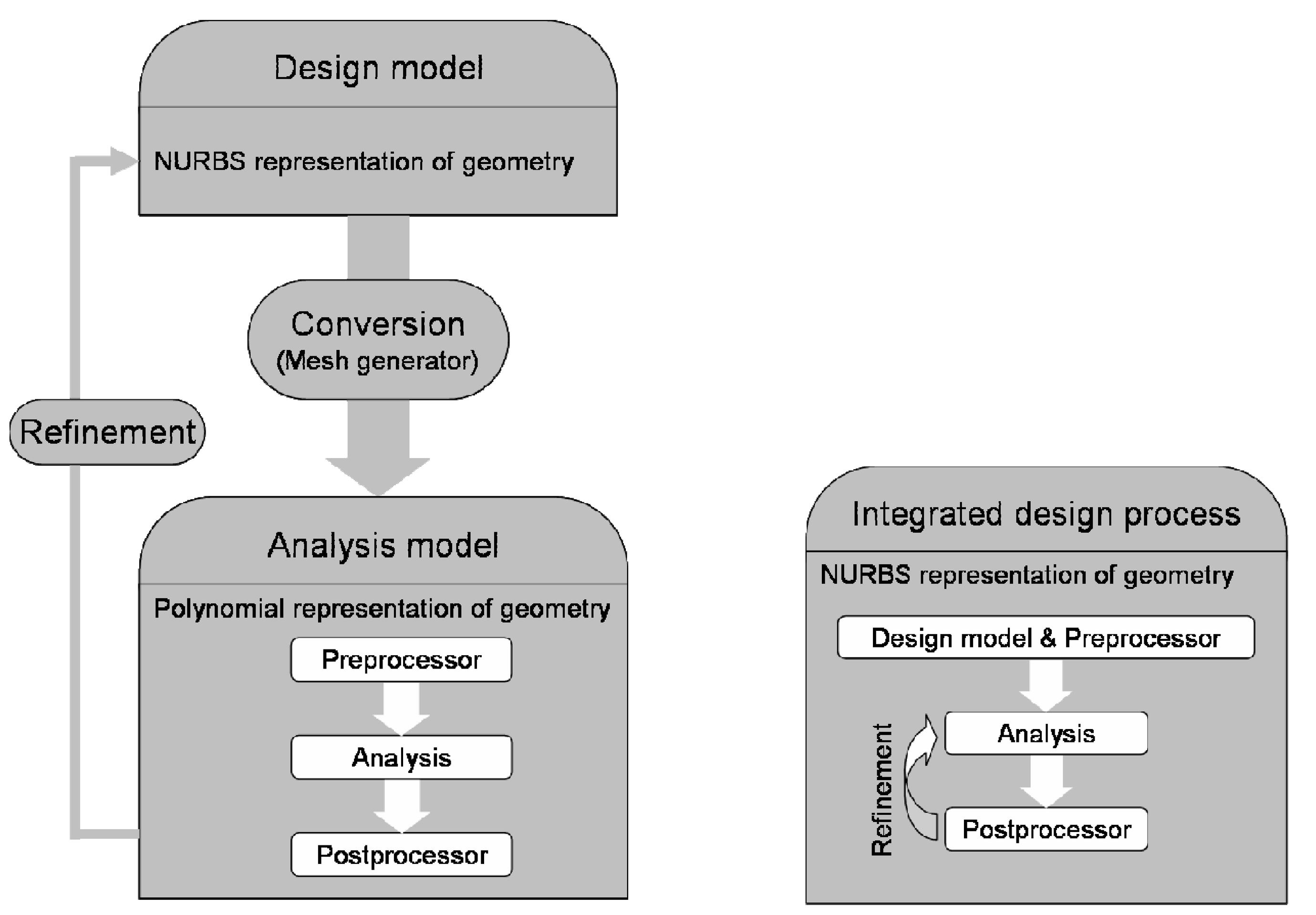
Historically, the fields of Computer Aided Design (CAD) and Computer Aided Engineering (CAE) have developed independently from each other and different mathematical descriptions are used in the two fields. This has lead to a gap between design and analysis models that has to be bridged by model conversion. This model conversion (meshing) often is the most time-consuming step in the design-through-analysis process. Isogeometric analysis is a new development in computational analysis which aims to close this gap by using the same mathematical description for the design and the analysis model. NURBS (Non-Uniform Rational B-Splines) are the most widespread functions in CAD and hence they are used as basis functions for the isogeometric analysis. At the Chair of Structural Analysis we use this concept for the structural analysis and shape optimization of thin shells.

Motivation:

Isogeometric Analysis (IGA) merges the models for design and analysis into one. Therefore no model conversion is needed and refinement can be performed on the analysis model while the exact geometry is preserved in each refinement level. Furthermore, the smoothness of the NURBS ensures higher accuracy compared to standard polynomials which are commonly used in the "traditional" Finite Element Analysis (FEA). Another important idea behind IGA is the "isoparametric concept" i.e. the same basis is used to model the geometry and to approximate the unknown solution fields.

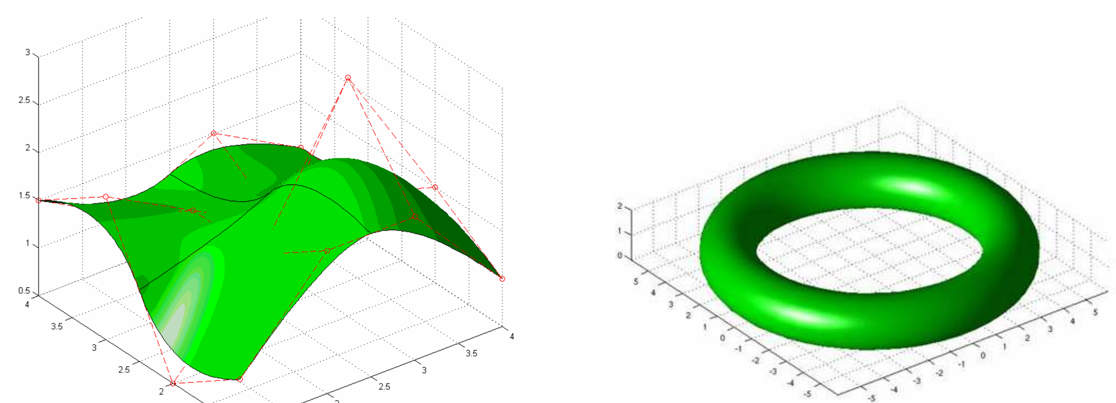
Design-through-analysis process in FEA and IGA



"traditional" FEA approach

isogeometric approach

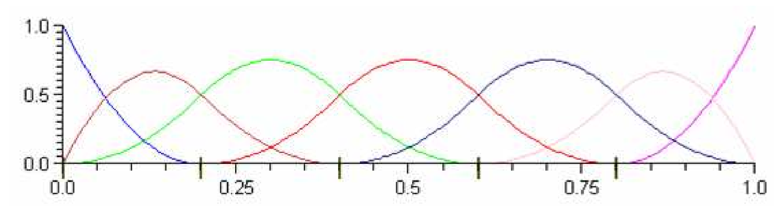
NURBS as basis for geometry and analysis



NURBS surfaces

$$S_{i,j}(u,v)=\frac{\sum_{j=0}^{m}\sum_{i=0}^{n} N_{i,p}(u)\cdot M_{j,q}(v)\cdot w_{i,j}\cdot \mathbf{P}_{i,j}}{\sum_{j=0}^{m}\sum_{i=0}^{n} N_{i,p}(u)\cdot M_{j,q}(v)\cdot w_{i,j}}$$

$$N_{i,p}(u)=\frac{u-u_i}{u_{i+p}-u_i}N_{i,p-1}(u)+\frac{u_{i+p+1}-u}{u_{i+p+1}-u_{i+1}}N_{i+1,p-1}(u)$$



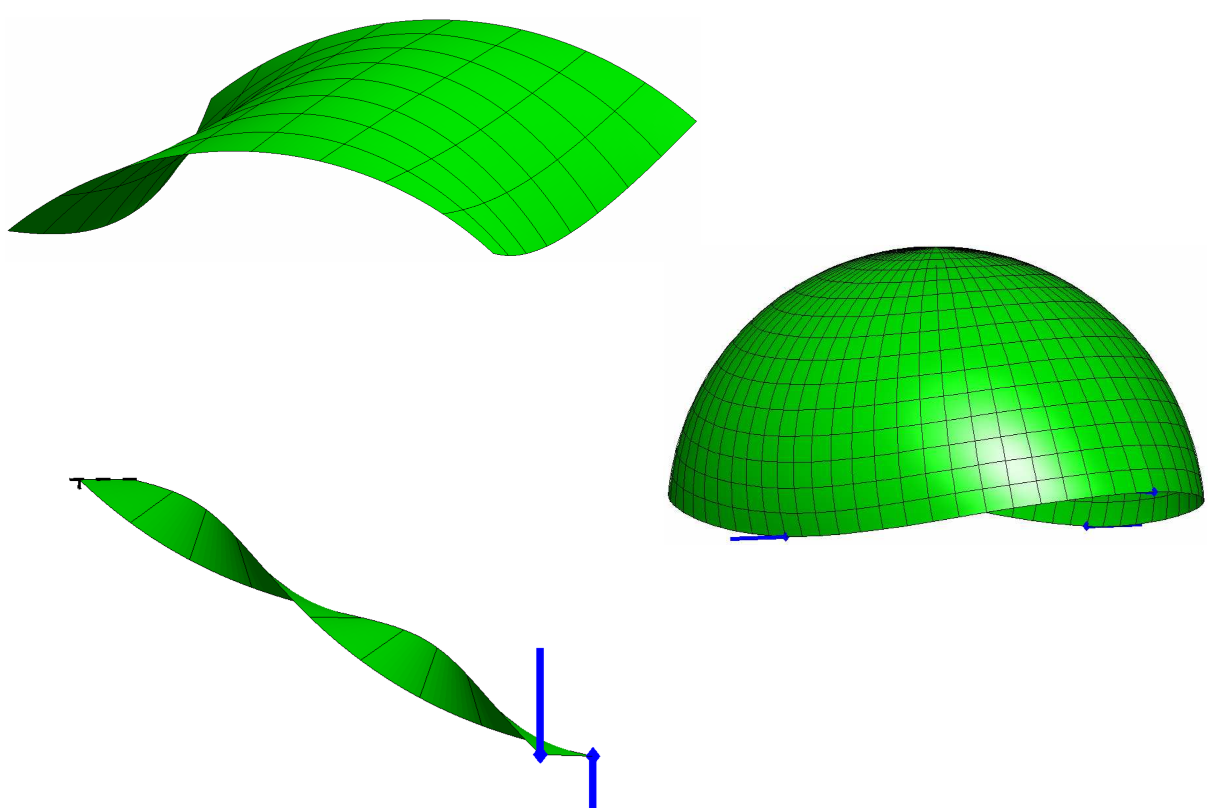
Basis functions

Isogeometric shell analysis:

We developed an isogeometric shell element based on the Kirchhoff-Love shell theory. Due to the higher order basis functions it is locking-free and no rotational degrees of freedom are used. Moreover, the isoparametric description is very advantageous in large deformation (geometrically nonlinear) structural analysis.

A CAD surface model can be used for the analysis without further modification. In shape optimization the three models for design, analysis and shape optimization are merged into one model and no transformation from a FE mesh back to a CAD geometry is necessary.

Isogeometric shell analysis

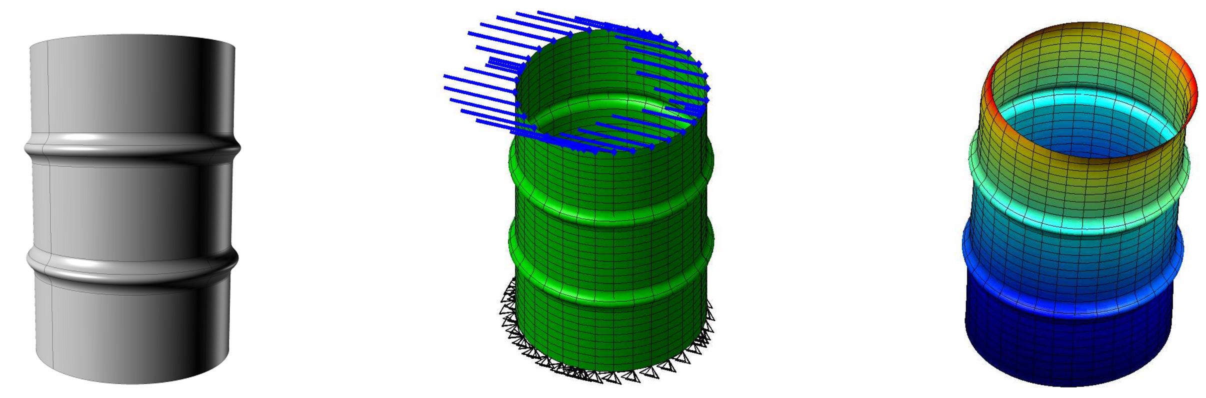


$$\delta W_{int} = -\int_V (\mathbf{S}:\delta\mathbf{E})\,dV$$

$$K_{rs}^{int} = -\frac{\partial^2 W_{int}}{\partial u_r\partial u_s} = \int_V\left(\frac{\partial \mathbf{S}}{\partial u_s}:\frac{\partial\mathbf{E}}{\partial u_r}+\mathbf{S}:\frac{\partial^2\mathbf{E}}{\partial u_r\partial u_s}\right)dV$$

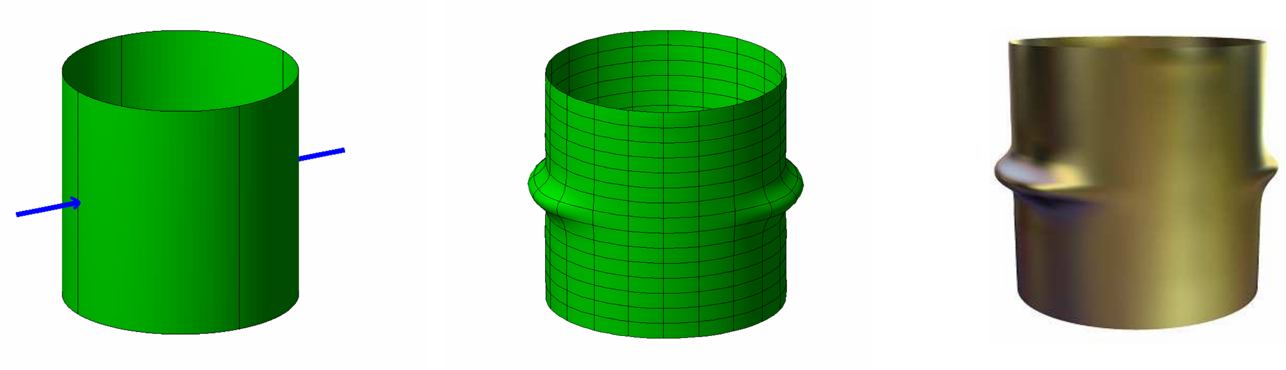
$$K_{rs}^{int} = \int_A\left(\frac{\partial \mathbf{n}}{\partial u_s}:\frac{\partial\varepsilon}{\partial u_r}+\mathbf{n}:\frac{\partial^2\varepsilon}{\partial u_r\partial u_s}+\frac{\partial\mathbf{m}}{\partial u_s}:\frac{\partial\kappa}{\partial u_r}+\mathbf{m}:\frac{\partial^2\kappa}{\partial u_r\partial u_s}\right)dA$$

Integration of CAD and IGA for thin-walled structures



CAD model | IGA model *geometry is preserved* | result (deformations)

Isogeometric shape optimization

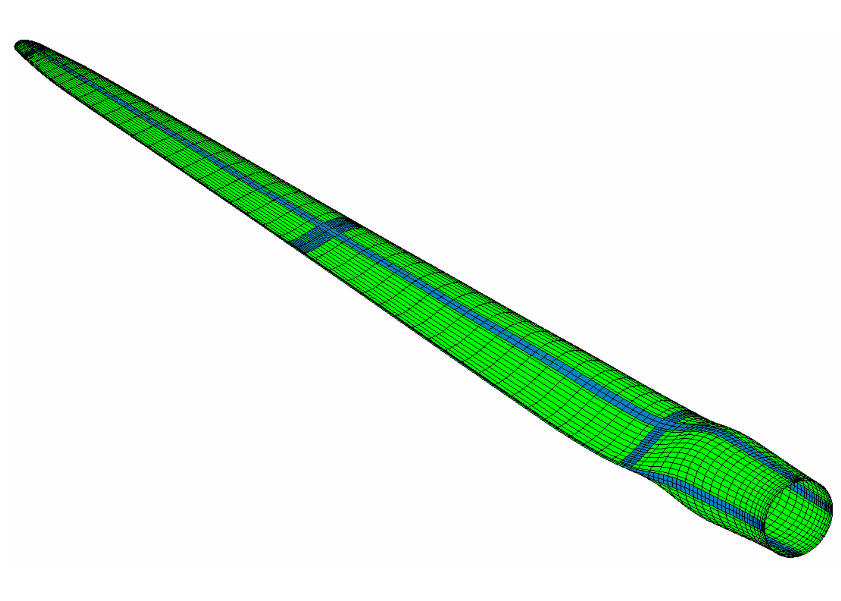


initial design | shape optimization | optimized design as CAD model

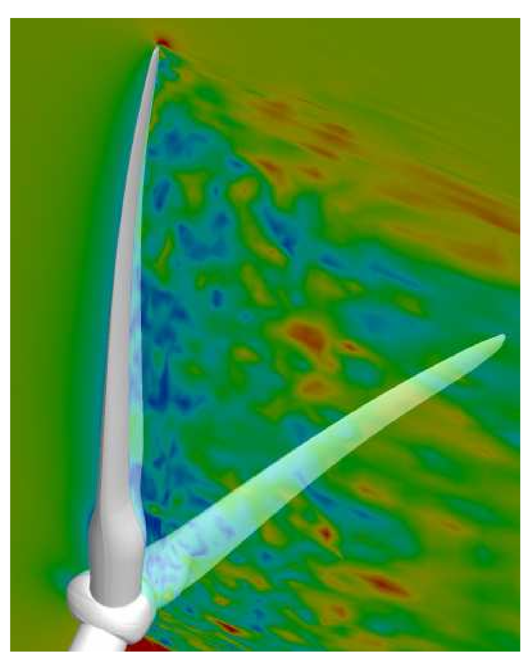
FSI analysis of a wind turbine blade:

This is a joint project with the Department of Structural Engineering at the University of California San Diego (UCSD). Our isogeometric shell formulation has been implemented into the isogeometric Fluid-Structure-Interaction (FSI) code of Prof. Bazilevs at UCSD and has been applied to the fully integrated computation of a wind turbine blade in air flow.

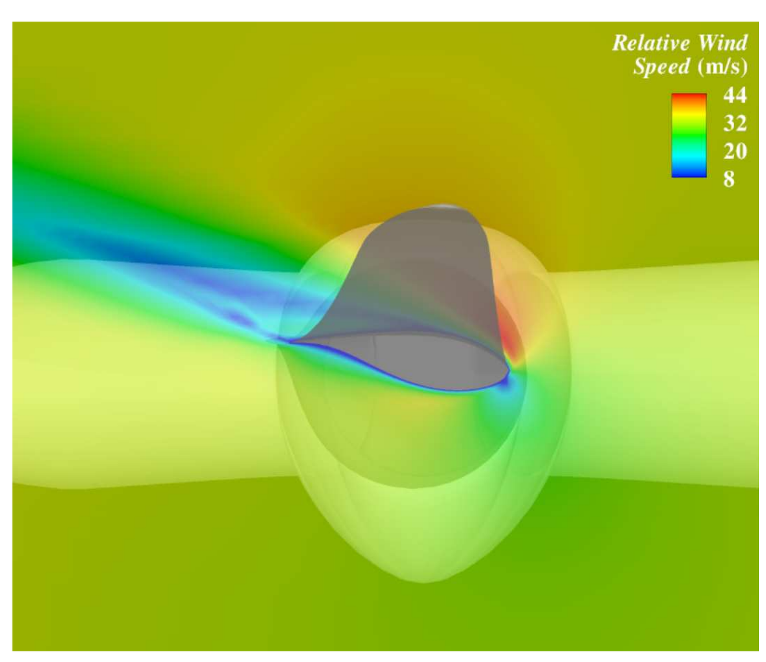
Isogeometric FSI analysis of a wind turbine blade



Wind turbine blade
16-patch NURBS model



FSI simulation
side view



FSI simulation
top view